Results from Yellowstone National Park

Winter Air Quality Study
2003-2004

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Summary results

Air pollutant concentrations for carbon monoxide (CO) and particulate matter (PM 2.5) were significantly lower in winter 2003-2004. A large part of the decreased in air pollutants was from lower numbers of snowmobiles entering the park (down 56%) which lead to a decrease in CO of 60% and PM2.5 by 40%. At Old Faithful, where most of the snowmobiles visit, CO was down by 23% and PM2.5 by 60%.

Introduction

Air quality monitoring was used during the winter 2003-2004 season at two locations in Yellowstone National Park as part of the adaptive management plan to determine the impact on air quality of implementing the Yellowstone Winter Use Plan. Several changes were expected to reduce the emissions from the snowmobiles, primarily the reduction in allowed daily entries and the clean engine technology that was required. Pre-sales of entry passes and required guides for rental snowmobiles were also required. Multiple court rulings during the season created a great deal of uncertainty and probably reduced the number of snowmobiles entering the park further.

Monitoring set up

The Old Faithful monitoring shelter was located to the east of the main parking lot for the Snow Lodge and south of the Old Faithful geyser. Instrumentation at the site included a nephelometer for collection of particle scattering, a Beta Attenuation Monitor (BAM) for collection of $PM_{2.5}$, a Carbon Monoxide (CO) analyzer, wind speed/wind direction sensors, ambient temperature, and relative humidity sensor. A time-lapse video camera and a digital camera were installed on the Park Rangers' station and overlooked the main vehicle parking lot. Figure 2 presents a photograph of the Old Faithful monitoring site.

The Old Faithful shelter was located within 50 feet of one of the warming huts in the Old Faithful visitor area. The warming huts were warmed by wood-burning stoves from about 7:30 am until early evening. At times, the smoke from the stack could be seen blowing directly at the air quality shelter. Figure 2-3 presents a photograph of the warming hut and the Old Faithful shelter with smoke visible from the warming hut exhaust..

The State of Montana collected carbon monoxide, $PM_{2.5}$, and meteorological data at the West Entrance of the park in a cooperative effort. This data was retrieved from EPA AIRS and directly from the State of Montana. All data collection, validation, and quality assurance steps were performed by the State of Montana.

Table 1. List of monitoring equipment at the two Yellowstone NP monitoring locations in the 2003-2004

Site Name	Sampler	Sampler Type	Sampler Model No.	Averaging Period	Sample Frequency
Old Faithful	Particulate	BAM $PM_{2.5}$ (Thermo-Andersen)	FH 62 C14	1-hour	Continuous
	Gaseous	CO Analyzer (Thermo Environmental)	TEI 48C	1-hour	Continuous
	Meteorological	Wind Speed and Wind Direction (R.M. Young)	05305	1-hour	Continuous
	Meteorological	Primary Ambient Temperature and Relative Humidity (Rotronics)	MP101A-C4	1-hour	Continuous
	Meteorological	Secondary Ambient Temperature and Relative Humidity (Rotronics)	MP101A-C4	5-min	Continuous
	Photographic	Digital Camera (Kodak)	HRDC-1	--	Every 15 minutes
	Time lapse video	Time Lapse Recorder (Panasonic)	SVHS	4-seconds	continuous
	Optical	Nephelometer (Optec)	NGN-2	2-min (every 5-min)	Continuous
West Entrance **	Particulate	BAM $PM_{2.5}$ (Met One)	BAM 1020	1-hour	Continuous
	Gaseous	CO Analyzer (Advanced Pollution Instruments)	API 300	1-hour	Continuous
	Meteorological	Ambient Temperature, Wind Speed, and Wind direction (Climatronics)	--	1-hour	Continuous

** Equipment provided and operated by the Montana Dept. of Environmental Quality

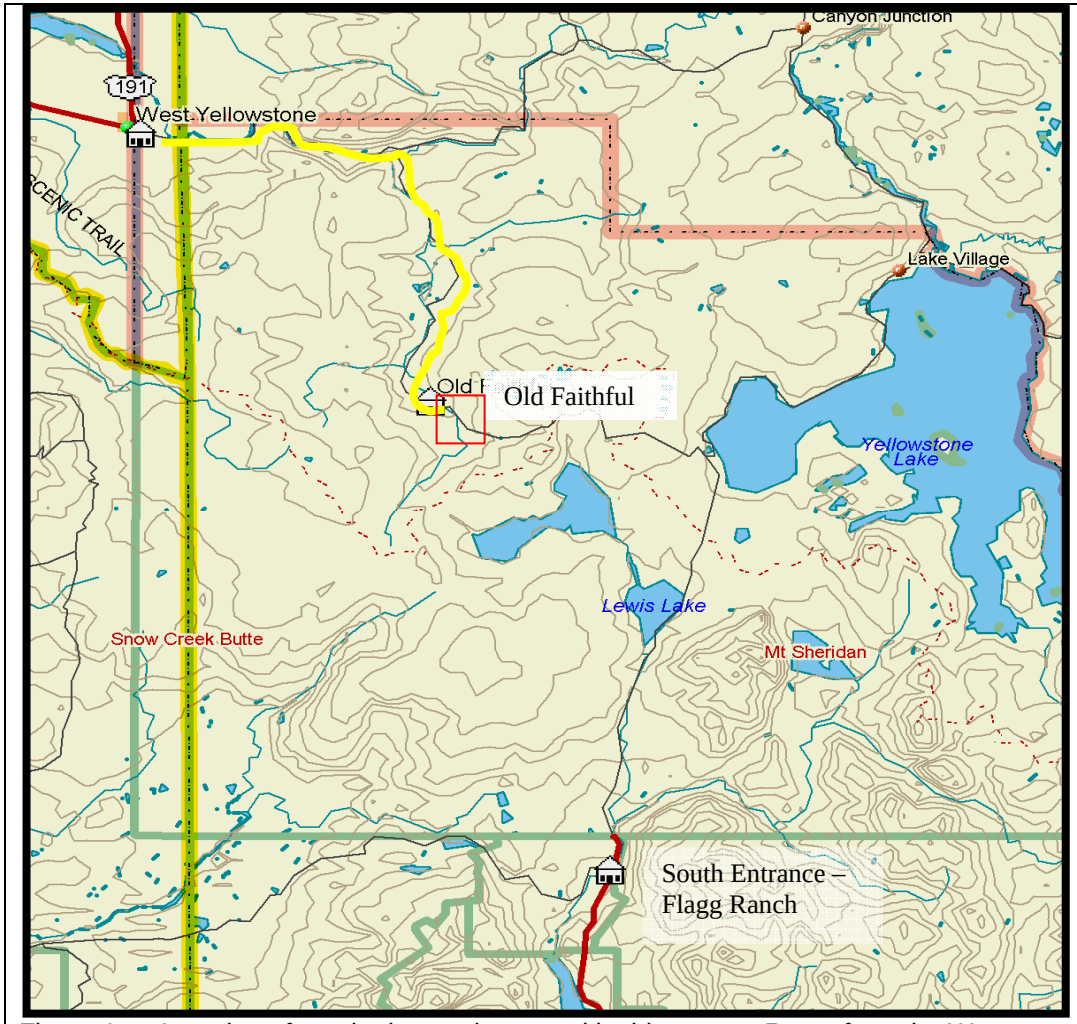


Figure 1.a Location of monitoring stations used in this report. Route from the West entrance to Old Faithful is highlighted in yellow.

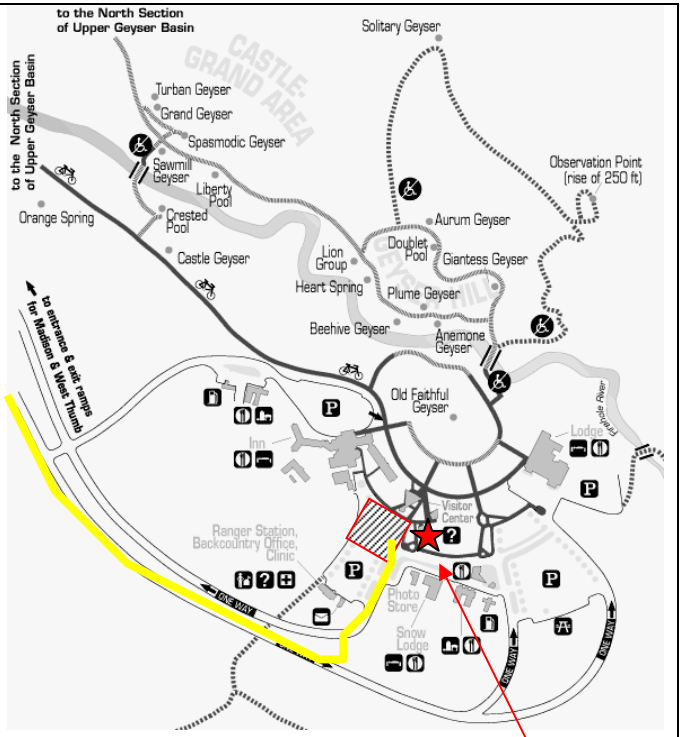


Figure 1.b Location of air quality shelter at Old Faithful. Entry route and parking area for the snowmobiles is shown. Shelter is downwind and across from the parking area.

Figure 2.a The air quality shelter was adjacent to the warming hut. Steam from Old Faithful can be seen in the background and wood smoke is coming from a pipe on the warming hut. The parking area is to the left of this picture.

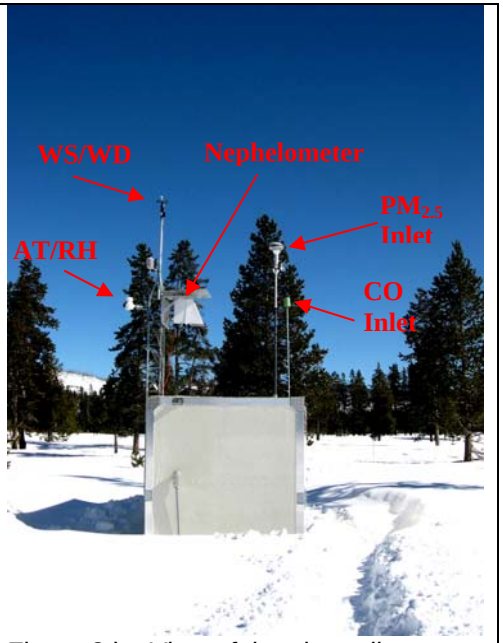


Figure 2.b View of the air quality shelter at Old Faithful. The nephelometer and meteorological sensors are on the left and the intakes for CO and PM on the right side of the shelter.

Results and discussion

Summary and Comparison of Stations

Comparison to the Standards

Two air quality monitoring stations in Yellowstone were operational through the 2003-2004 winter season at the West Entrance and Old Faithful. The table on the right summarizes particulates as PM 2.5 and carbon monoxide (CO) concentrations for time periods relevant to the national standards.

- None of the observed pollutants exceeded the national standards during the reporting period.
- The West Entrance has larger CO concentrations than either the Flagg Ranch or Old Faithful areas. In contrast, the Old Faithful area has greater PM2.5 values; sometimes much greater values.
- Wood smoke or another unknown emission source appears to be present at Old Faithful.

Summary tables

Table 2. Comparison of observed pollutant concentrations to the National Air Quality Standards.

Park:		Yellowstone				Grand Teton		
Location:		Old Faithful		West Entrance		Flagg Ranch		
Statistical Period	Winter season → parameter ↓	2002 - 2003	2003 - 2004	2002 - 2003	2003 - 2004	2002 - 2003	2003 - 2004	Units
Max 1-hr	PM2.5	200	151	81	29	8	- -	ug/m3
Max 24-hr	PM2.5	41	17	15	9	8	- -	ug/m3
% of Std	PM2.5			23%		13%	- -	percent
Avg	PM2.5	7	4.9	8.2	4.0	5	- -	ug/m3
90th percentile	PM2.5	12	9	18	8	9	- -	ug/m3
Max 1-hr	CO	2.9	2.2	8.6	6.4	4.7	- -	ppm
% of Std	CO	8%	6%	25%	18%	13%	- -	percent
Max 8-hr	CO	1.2	0.9	3.3	1.3	1.7	- -	ppm
% of Std	CO	13%		37%		19%	- -	percent
Avg	CO	0.24	0.26	0.57	0.26	0.25	- -	ppm
90th percentile	CO	0.5	0.5	1.3	0.5	0.6	- -	ppm
Avg	BSPD		32.2				- -	
90th percentile	BSPD		56.4				- -	

PM2.5 - Particulate matter that is 2.5 microns or less in size.
CO - carbon monoxide gas
BSPD - nepthelometer scattering coefficient

Table 3. Trends Summary for CO and $PM_{2.5}$ by monitoring location

Trends in Winter Air Quality

Both air pollutants, CO and PM2.5, have decreased considerably at the monitoring locations in Yellowstone NP where snowmobile traffic is heavy. At the West Entrance the snowmobile traffic pattern is such that relatively high pollutant levels are seen in the morning and afternoon "rush hours", however, when these values are averaged over 8 hours with lower night-time or mid-day values, the concentrations are above the background concentrations, but less than the threshold for the national ambient standard for CO or PM.

At the Old faithful, the snowmobile traffic is later (between 10am and 2pm) and spread out a bit more than at the entrance stations.

- Both CO and PM were significantly lower for winter 2003-2004
- The trend in CO is to much lower concentrations at the West Entrance. CO has decreased by at least a factor of 4 since the 1998-1999 winter season.

Location	Year	1-hr CO (ppm)[1]		8-hr CO (ppm)[2]		24-hr $PM_{2.5}$ (ug/m^3)[3]	
		1st Max	2nd Max	1st Max	2nd Max	1st Value	98th% Value
West Yellowstone	1998-1999	18.2	11.1	8.9	4.3	NA	NA
West Yellowstone	1999-2000	13.5	13.1	5.4	4.7	NA	NA
West Yellowstone	2000-2001	17.9	17.4	6.0	5.3	NA	NA
West Yellowstone	2001-2002	16.0	13.7	5.4	4.9	NA	NA
West Yellowstone	2002-2003	7.9	3.4	3.3	1.7	19.2	16.4
West Yellowstone	2003-2004	6.4	3.1	1.3	1.1	9.0	7.0
Old Faithful	2002-2003	2.9	2.0	1.2	1.0	41.0	22.3
Old Faithful	2003-2004	2.2	1.7	0.9	0.9	16.5	14.5
Flagg Ranch	2002-2003	4.7	3.1	1.7	1.1	16.4	10.7
National AAQS		---	35	---	9	---	65
Montana AAQS		---	23	---	9	---	65

NA - Not Available

[1]The 1-hour CO NAAQS is based on the 2nd maximum concentration.

[2]The 8-hour CO NAAQS is based on the 2nd maximum concentration.

[3]The 24-hour $PM_{2.5}$ NAAQS is based on the 3-year average of the 98th percentile of 24-hour $PM_{2.5}$ concentrations; however, no more than two years of data is available for park monitors. The annual 98th percentile is given only to demonstrate the improvement between winter seasons. Comparison with the annual standard is not shown.

West Entrance

Relationship of Pollutants to Traffic

The amount of winter snowmobile traffic and the maximum hourly CO or second highest daily 8-hr CO correlates well (figures 3 & 4). Less snowmobile traffic leads to lower observed CO. Compared to the peak snowmobile traffic year, the traffic was down 71% in winter 2003-2004 while the 8-hr average CO pollution decreased by 78%.

The measured CO at Flagg Ranch is lower than the other two locations where the snowmobile traffic is higher. As snowmobile traffic at Old Faithful decreases, the measured CO is declining to values closer to those at Flagg Ranch in 2002-2003.

Several other things can be seen from the figures. In figure 3, snowmobile traffic generally increasing between 1988 and 2002, however, the 1-hr maximum CO didn't follow the tend in proportion. Two factors are expected to account for this: weather variables and the number of snowmobiles waiting in queues. The lower correlation coefficient for the 1-hr maximum CO to traffic counts reflects the short term variability. The longer average 8-hr CO measurements have a stronger correlation and are less sensitive to the morning queue.

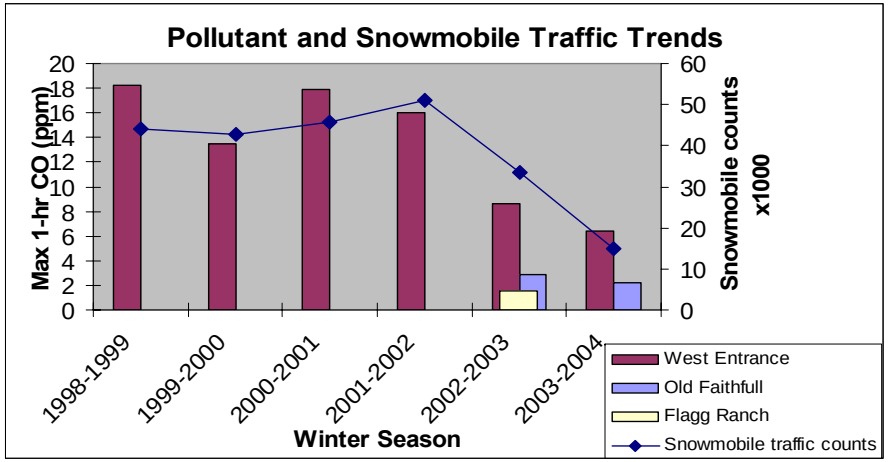


Figure 3. The highest observed hourly CO concentration for the years and locations that had monitoring are compared to the winter season snowmobile traffic counts at the West entrance.

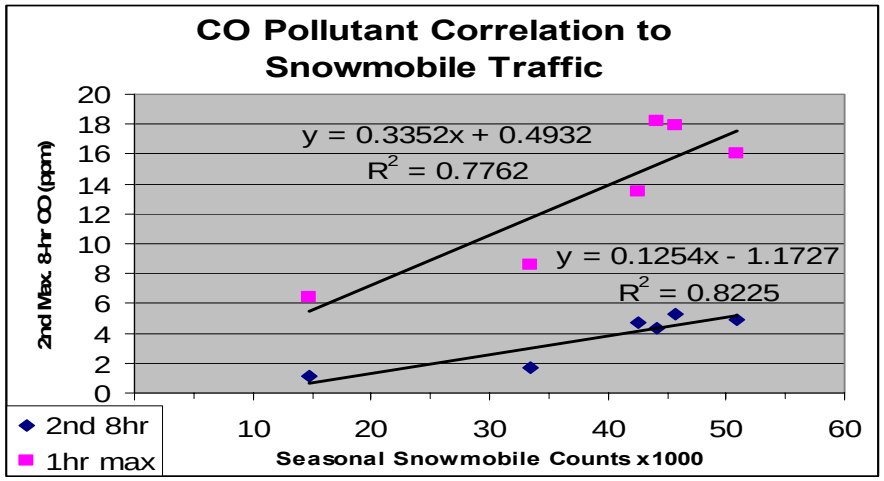


Figure 4. The CO concentrations for two different averaging periods are compared to the snowmobile counts at Yellowstone for 1998 to 2004. As the amount of snowmobile traffic increases the likelihood of high 1-hour or 8-hour CO concentrations increases.

Improvements in Air Quality

Snowmobile traffic counts were down considerably in winter 2003-2004, both because of the Yellowstone Winter Use Plan and the court orders that interrupted the season. West entrance counts were down 56%, which was reflected in the average CO (down 54%) and the 90th percentile (down 62%). The short-term peak CO is less dependent on the overall counts, instead following the peak number of snowmobiles near the entrance station at one time. Thus, peak CO at the west entrance station is down only 26%.

At Old faithful the situation is somewhat different. Snowmobile usage in the Old faithful area was visually observed by digital camera to be greatly decreased compared to the winter before. Based on snowmobile entrance numbers, activity at Old Faithful may have approached a decrease of 50%. The maximum 1-hr and 8-hr CO concentrations decreased by only 23%, however, the change in the average and the 90th percentile CO was positive, but within the measurement error of the analyzer.

Table 4a. Comparison of winter season snowmobile counts and CO pollutant concentrations.

Park	Location	Winter season	Snowmobile Entrance counts	ppm Max 1-hr CO	percent of Std CO	ppm Max 8-hr CO	percent of Std CO	ppm Avg CO	ppm 90th % CO ##
YELL	Old Faithful	2002 - 2003	* 45,035	2.9	8%	1.2	13%	0.24	0.5
		2003 - 2004	* 21,227	2.2	6%	0.9	10%	0.26	0.5
YELL	West Entrance	2002 - 2003	33,458	8.6	25%	3.3	37%	0.57	1.3
		2003 - 2004	14,756	6.4	18%	1.3	14%	0.26	0.5
GRTE	Flagg Ranch	2002 - 2003	11,577	4.7	13%	1.7	19%	0.25	0.6
		2003 - 2004	6,471	- -	- -	- -	- -	- -	- -

Table 4b. Change in CO pollutant concentrations between winter seasons.

Units change	Old Faithful	- - -	(23,808)	0.7	- - -	0.3	0.0	(0.02)	(0.0)
	West Entrance	- - -	(18,702)	2.2	- - -	2.0	0.2	0.3	0.8
Percent change	Old Faithful	- - -	-53%	-24%	- - -	-23%	-23%	8%	2%
	West Entrance	- - -	-56%	-26%	- - -	-61%	-61%	-54%	-62%

* assumes most snowmobiles that enter the park go to Old Faithful.

Because the frequency distribution is skewed towards high CO concentrations, the maximum CO concentration are more like outliers. The 90th percentile is a more robust statistical way to look at the change in the higher CO concentrations.

PM2.5 is also related to snowmobile exhaust. At the West Entrance, the decrease in snowmobile traffic counts and the change in average PM2.5 and the 90th percentile were very similar at 56%. The 24-hr average PM2.5 decrease was only 40%. All averaging times and metrics showed a decrease in particulate matter.

At Old faithful, the average and 90th percentile PM2.5 decreased by about 27%. The 1-hr and 24-hr average PM2.5 had decreases of 24% and 60%.

Some caution is needed in interpreting the PM2.5 changes, because wood smoke would also be easily measured by the Beta Attenuation Monitor (BAM). The are sources of wood smoke near both monitoring locations and the timing of many PM2.5 events strongly suggests a source other than snowmobiles. The poor correlation between observed CO and PM2.5 further indicates that snowmobiles may not be the principal factor in PM2.5 concentrations at Old Faithful. A better comparison of the snowmobile contribution to PM2.5 at Old Faithful would be to limit the statistical comparisons to the 10am to 2 pm period when significant numbers of snowmobiles are present.

Table 5. Comparison of winter season snowmobile entrance counts and PM2.5 concentrations.

Park	Location	Winter season	Snowmobile Entrance counts	ug/m3 Max 1-hr PM2.5	ug/m3 Max 24-hr PM2.5	percent of Std PM2.5	ug/m3 Avg PM2.5	ug/m3 90th % PM2.5
YELL	Old Faithful	2002 - 2003	* 45,035	200	41	63%	7	12
		2003 - 2004	* 21,227	151	17	25%	4.9	9
YELL	West Entrance	2002 - 2003	33,458	81	15	23%	8.2	18
		2003 - 2004	14,756	29	9	14%	4.0	8
GRTE	Flagg Ranch	2002 - 2003	11,577	8	8	12%	5	9
		2003 - 2004	6,471					

Table 5b. Change between two winter seasons in PM2.5

	Old Faithful	- - -	(23,808)	48.9	24.5	- - -	1.9	3.4
	West Entrance	- - -	(18,702)	52.0	6.0	- - -	4.2	10.0
	Old Faithful	- - -	-53%	-24%	-60%	- - -	-28%	-27%
	West Entrance	- - -	-56%	-64%	-40%	- - -	-51%	-56%

Air quality comparisons between winter seasons

Figures 5a and 5b graphically show the changes in CO and PM2.5 by location over the last two winter seasons. The key feature to note is the reduction in pollutants at both monitored locations. If snowmobiles are the dominate PM source the ratio between CO and PM should be about the same at both the West Entrance and Old Faithful; that is not the case. Also, the decrease in PM2.5 over the last two winter seasons should have been about the same percent; Neither location matched the change in snowmobile traffic or changed the same amount.

Wood smoke from the nearby warming huts at Old Faithful and other area point sources (most likely the Snow Lodge) are contributing to the PM concentrations at Old Faithful This is observed visually by watching the smoke plumes and by the fact that large PM spikes are recorded at night and evening hours when no snowmobiles are present.

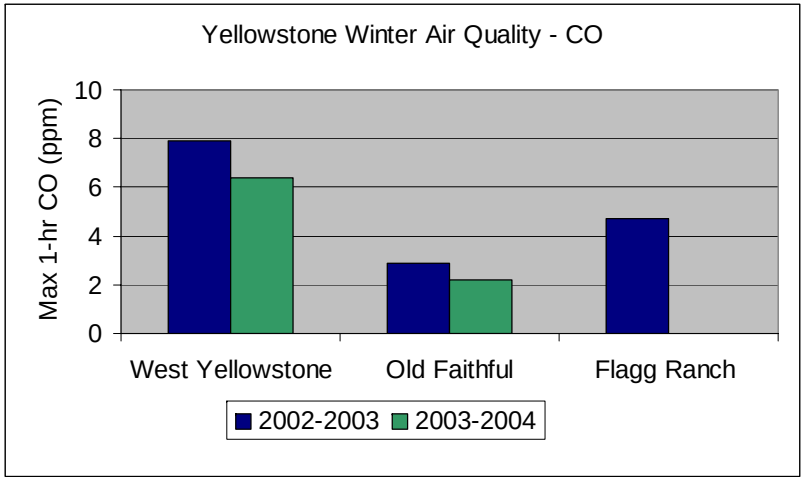


Figure 5a. Comparison of the maximum hourly CO for the 3 monitoring locations.

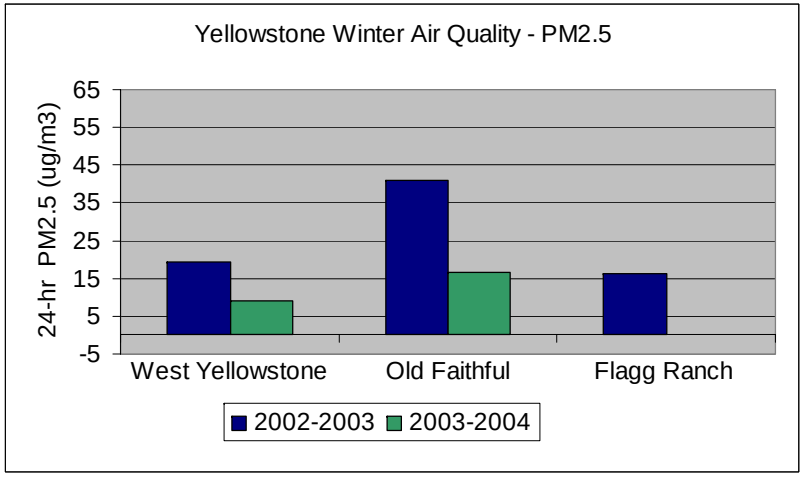


Figure 5.b Comparison of the 24-hour average PM 2.5 concentration for the 3 monitoring locations.

Details from the study

Pollutant characteristics in relation to snowmobiles

In this section we look at daily snowmobile activity and pollutant concentrations observed at the West Entrance and at Old faithful.

Snowmobile Activity

Park staff count vehicle entry and consolidate the record by hour. The graphic in figure 6 indicates the mean (bar within box), 75th percentile (box), and max/min (line with end bar) for snowmobile counts for the whole season. Most of the traffic is between 8 and 10 am, with a peak after 9am. There is no count of the exiting snowmobiles, but most are reported to exit between 3 and 5 pm.

Detail on the snowmobile activity by time of day for the West Entrance.

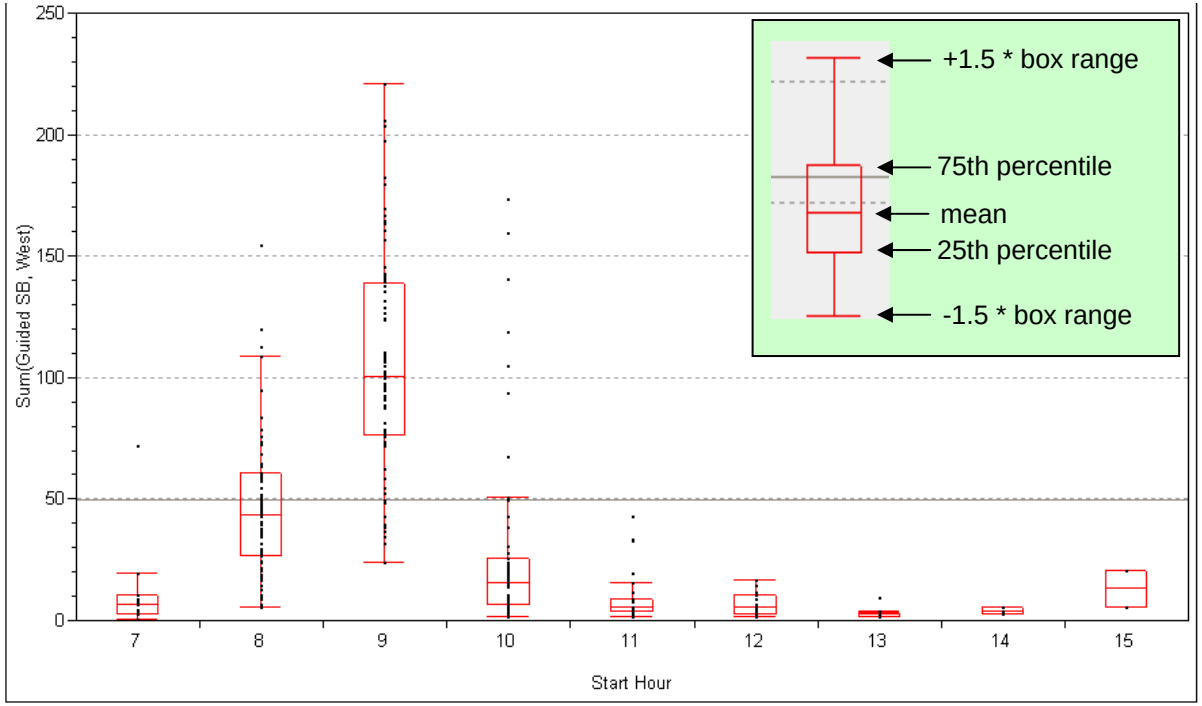


Figure 6. Statistical look at the hourly numbers of entering snowmobiles at the West Entrance. Most entries are between 8 and 11 am. No statistics are collected on the snowmobiles exiting through the west Entrance gate.

The hourly CO concentration box plots strongly resemble the snowmobile entry counts by hour of day. The peak CO is between 9 – 10 am. There is also a secondary peak in CO between 4 pm and 6 pm. These correspond to entry and exit periods of the snowmobiles.

Hourly CO concentrations at the West Entrance.

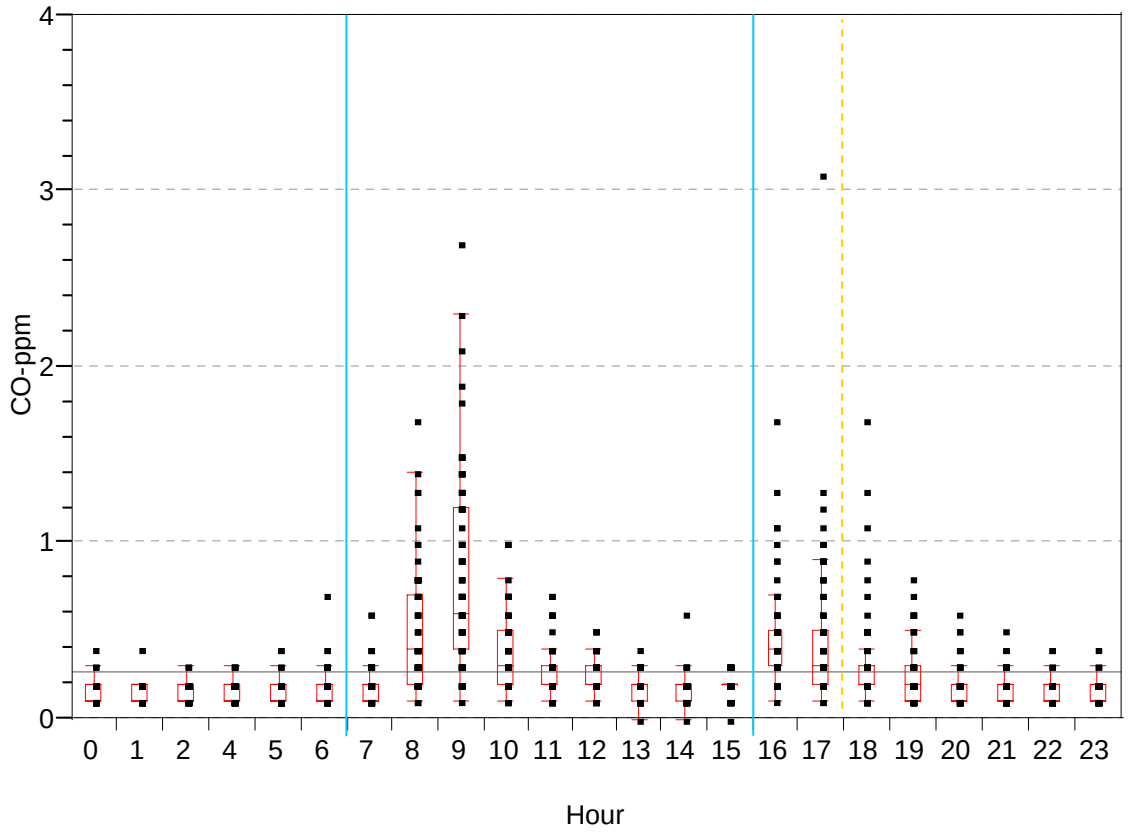


Figure 7 Statistical look at he hourly CO concentrations for the 2003-2004 winter season at the West Entrance. The overnight background is about 0.1 ppm. Snowmobile activity corresponds to greatly increased CO concentrations in the area.

Compare the box plot statistics for the PM2.5 by hour of the day (figure 8a and 8b). There is a peak PM2.5 at 9 – 10 am, but no afternoon secondary peak that would correspond to snowmobile traffic leaving the park. The other noticeable feature is the high degree of scatter caused by the hourly high values being much less regular than is seen in the CO or traffic count box plots.

The conclusion from this is that the snowmobile traffic contributes to the PM2.5, but is not the only source in the area or, perhaps, even the dominate source in the area. This observation is consistent with the lower aerosol emissions expected from 4-stroke engines that are being used in the majority of snowmobiles.

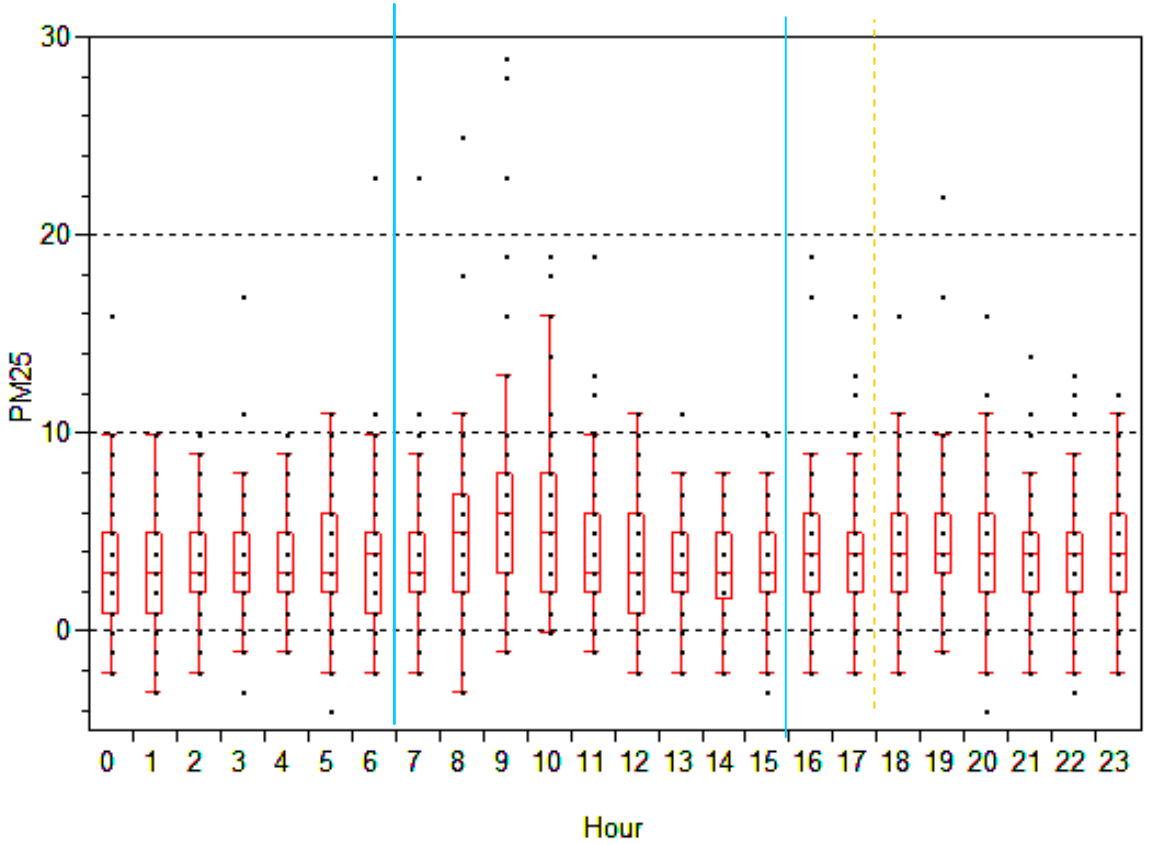


Figure 8a. Statistical look at the hourly PM 2.5 at the West entrance. Only modest increases in PM are seen during the morning and afternoon high-activity periods for snowmobiles.

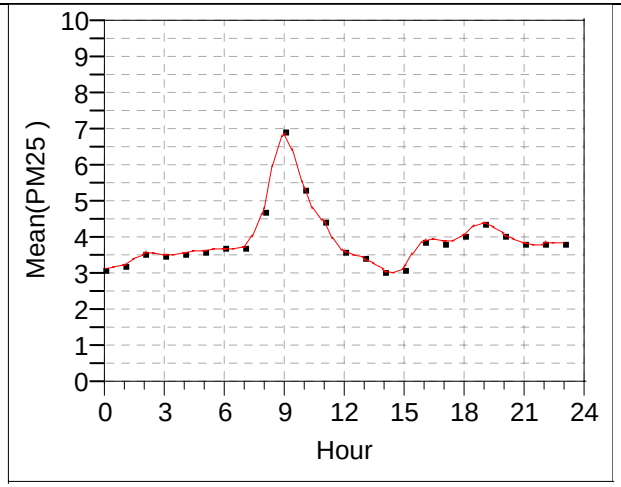
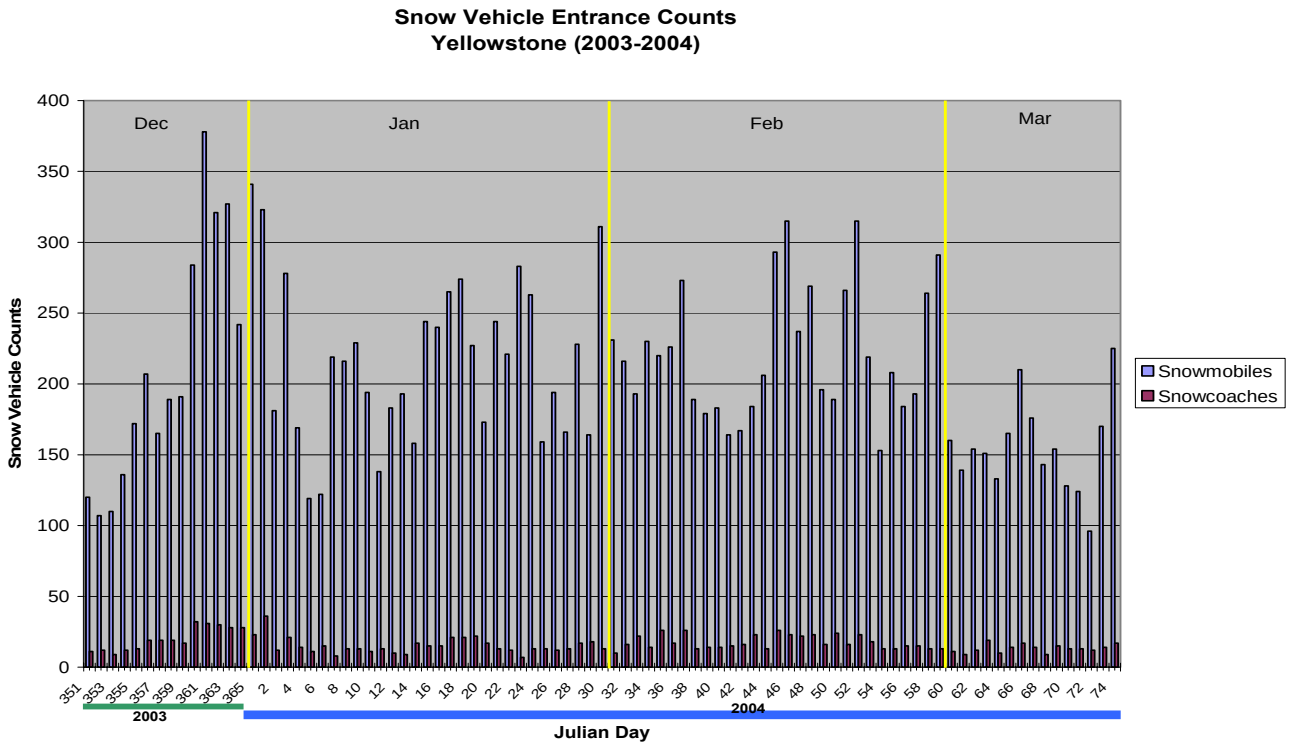


Figure 8b. Mean PM2.5 by hour of day for the winter season at the West Entrance station. Peak PM2.5 corresponds to peak period for snowmobile entries.



Date	Event	Julian day	Day of week
Dec 25	Christmas day	359	Thursday
		360	Friday
		361	Saturday
		362	Sunday
Jan 1	New Years day	1	Thursday
Jan 2	park closed	2	Friday
Jan 19	ML BD holiday	19	Monday
Feb 16	presidents holiday	47	Monday

Figure 7. Snowmobile traffic into Yellowstone from the West entrance is not uniform. The holiday period in December and the holiday weekends in February tend to have high daily counts. Activity begins to taper off in March.

Observed max. daily CO by day of the week
(Sun=1))

Day of week traffic activity

The graph above indicates a dual mode. The nephelometer and BAM both see increasing particle concentrations in one mode. In the other mode, only the nephelometer responses and the BAM measured particle concentrations are low. The second mode is most likely snow or fog picked up by the nephelometer, but not recorded by the BAM.

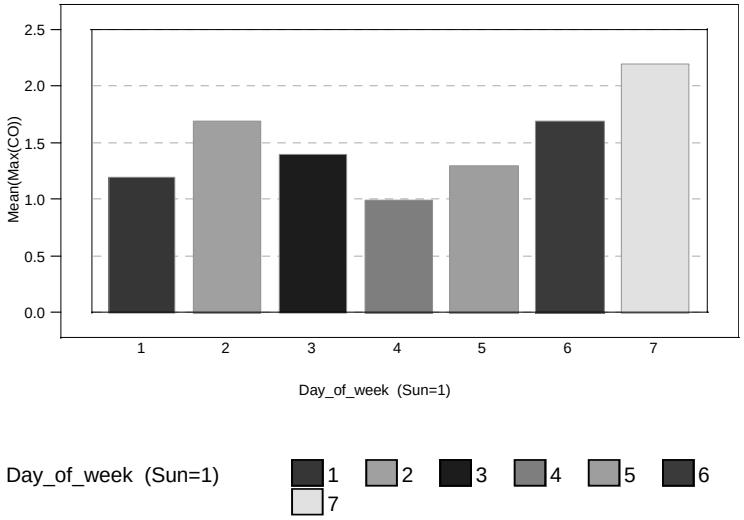
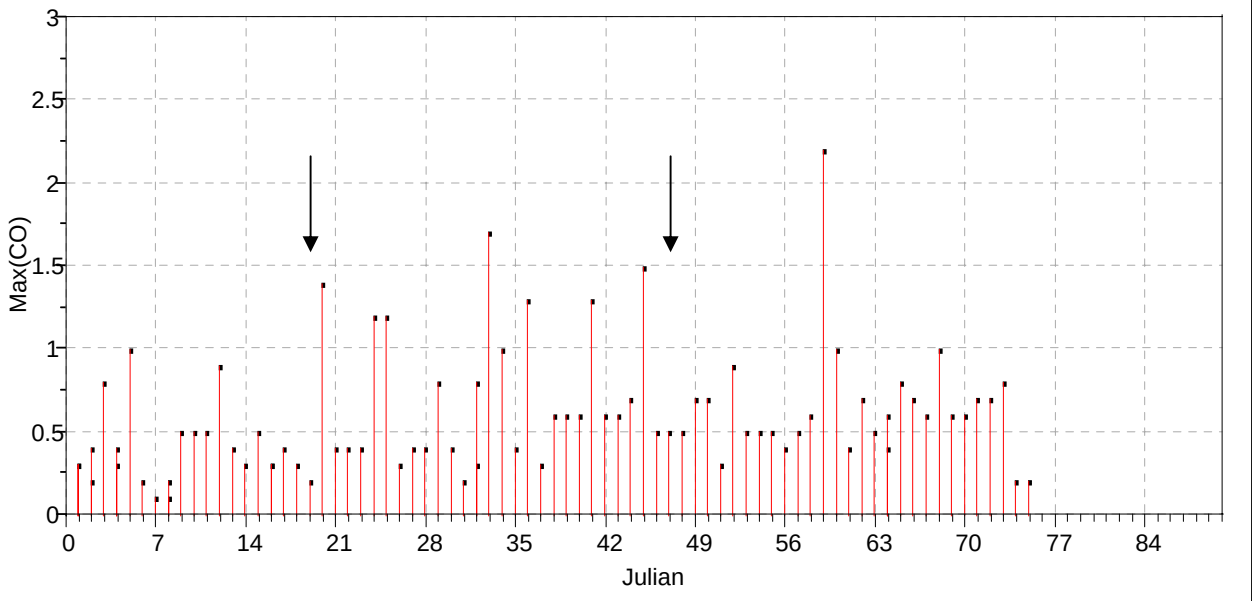


Figure 8. The maximum daily CO concentration and the snowmobile traffic counts vary by day of the week. CO concentrations are highest on Saturdays, followed by Friday and Monday as the next highest.



Date	Event	Julian day	Day of week
Jan 1	New Years day	1	Thursday
Jan 19	ML BD holiday	19	Monday
Feb 16	presidents holiday	47	Monday

Figure 9. The maximum hourly CO concentrations depend on more than just the amount of snowmobile activity. Compare the traffic counts in figure 7 to the CO concentrations.

PM2.5 at the West Entrance 2003-2004

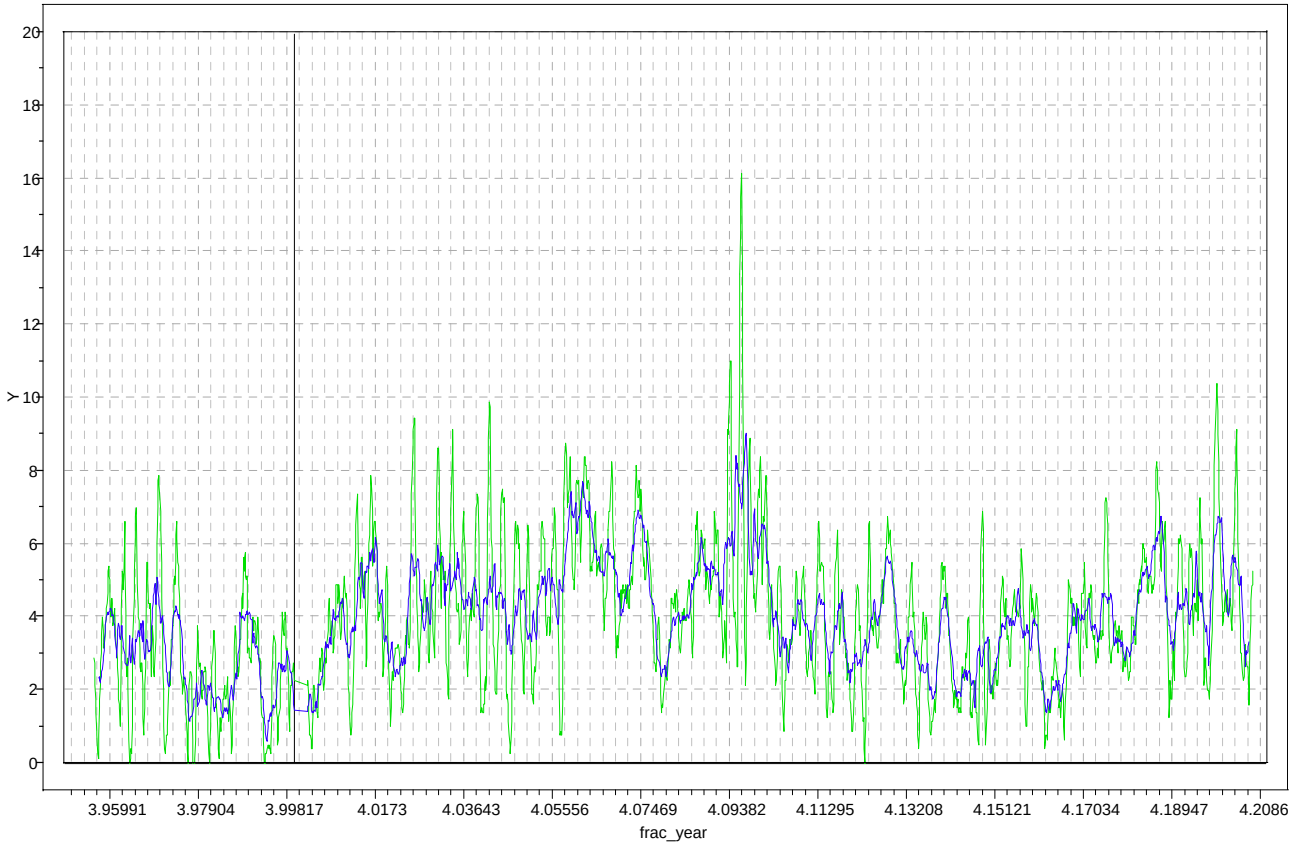
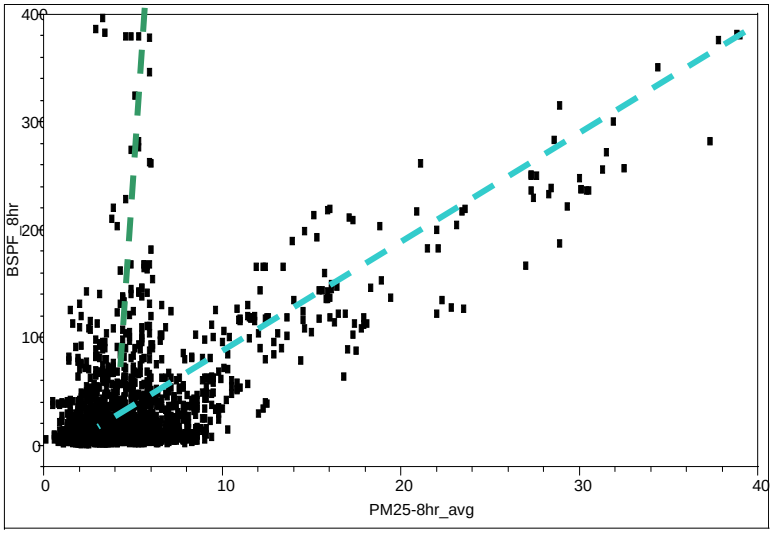


Figure 10. The PM 2.5 concentrations at the West entrance do not follow the snowmobile traffic counts. There are daily spikes and overnight low values in PM2.5. Peak values were observed on Feb 2 and 3 between 9-10am. No connection was determined for PM2.5 with either wind direction or wind speed.

The nephelometer measures the laser light scattering by small particles. Usually the information is related to the degree of visibility impairment rather than just to the mass of the particles in the air.

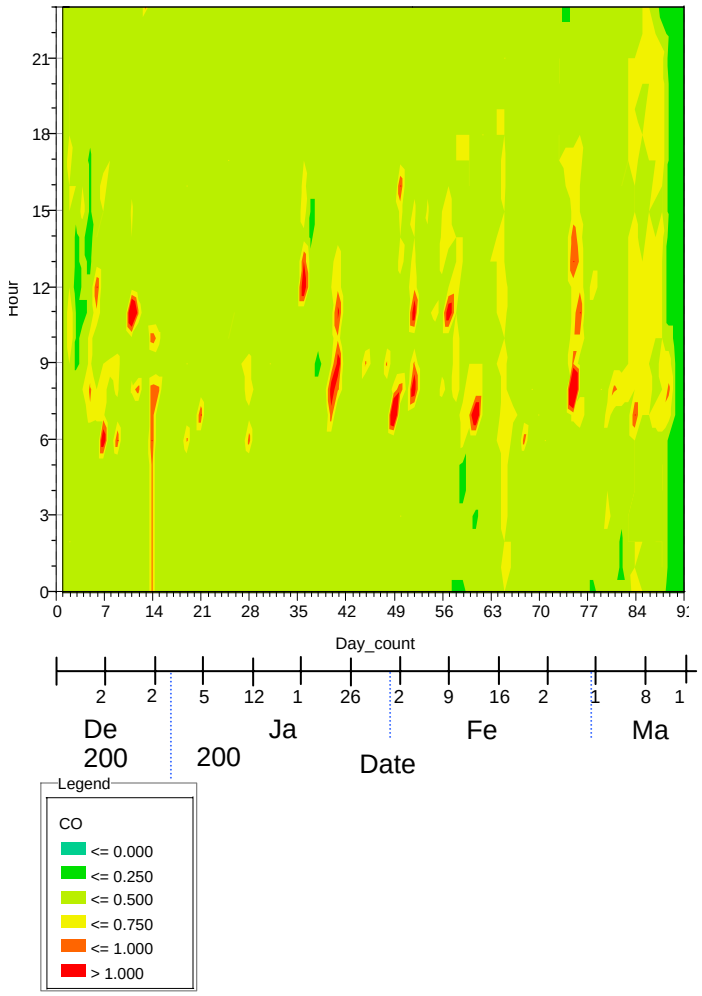
When the PM mass (from the BAM) is plotted vs the light scattering (B_{scat}) two correlations are observed. The dashed blue lines approximate the correlations in the figure. The interpretation of this observation is that particles with different light scattering characteristics are present which are likely from two different sources.

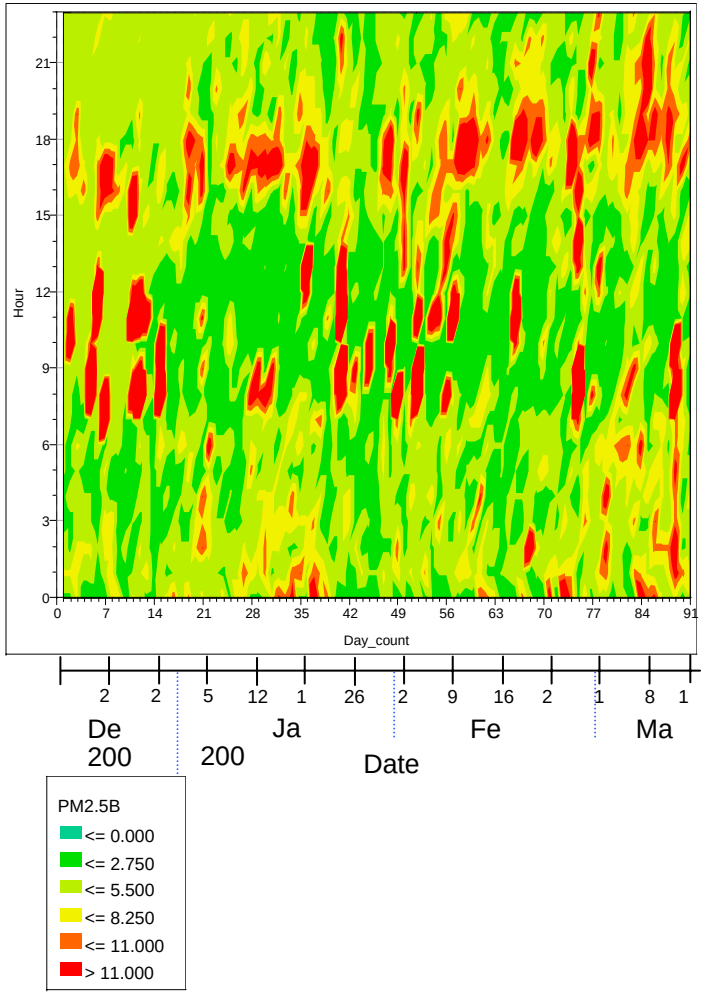


Bivariate Fit of BSPF_8hr By PM25-8hr_avg

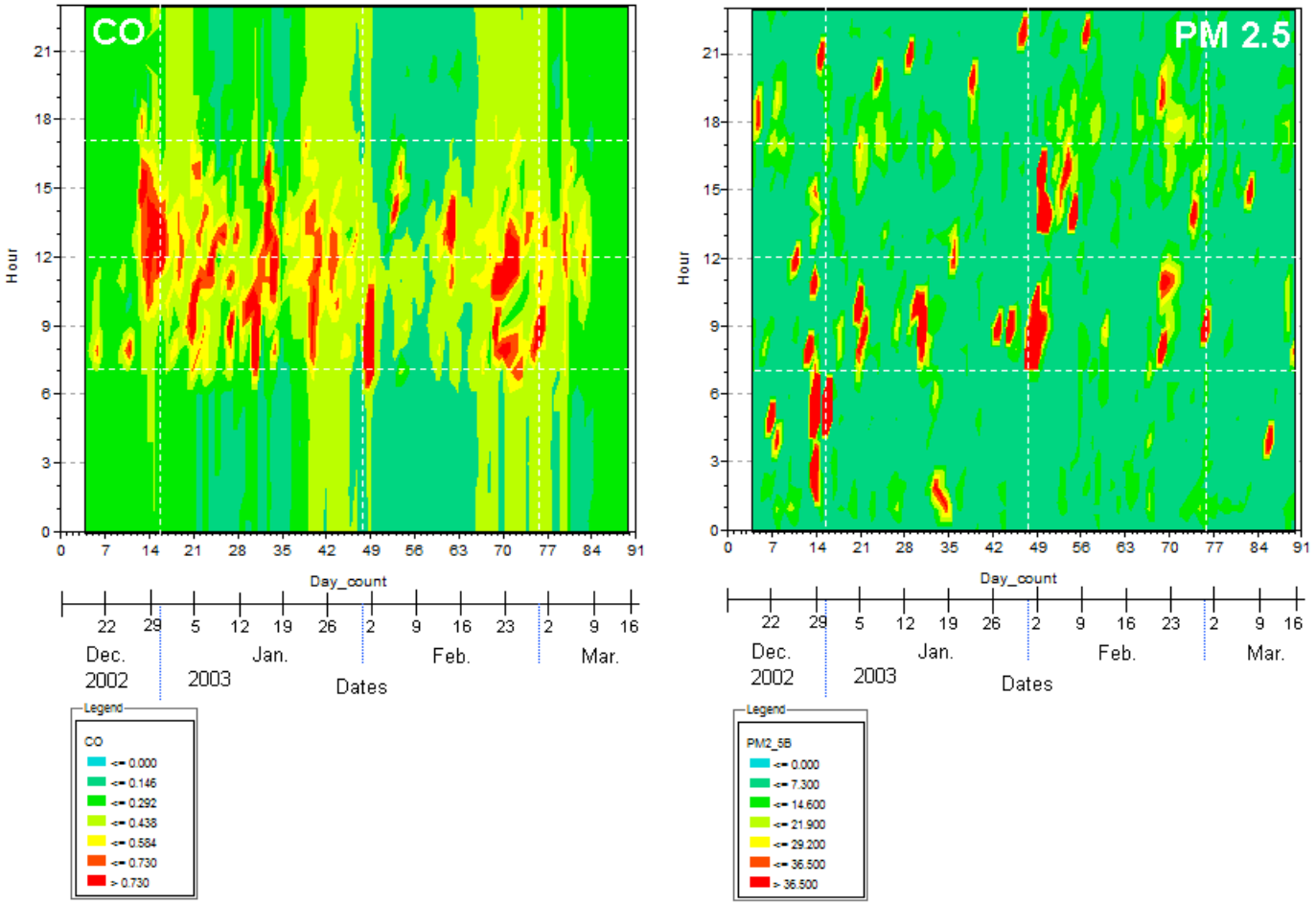
Nephelometer data from Old Faithful. The two correlation lines (blue dashed) indicate two different types of particles.

Comparison of CO and PM 2.5 Concentrations
Old Faithful, Yellowstone National Park





Comparison of CO and PM 2.5 Concentrations
Old Faithful, Yellowstone National Park
2002 - 2003



The above graphics of CO and PM by day and hour of day give a good visual way of seeing when concentrations are high (red areas). The CO and PM often have different periods when the high values are observed. PM high values are observed during periods when snowmobiles are not present at Old faithful. Some differences are also observed between years, the most notable is the reduction in concentrations.

References

Yellowstone Winter Use Plan

Data Transmittal Report for the Yellowstone National Park Winter Use Air Quality Study, December 16, 2003 – March 15, 2004, prepared by Air Resource Specialists, Sept. 3, 2004.